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A STUDY OF HABIT FACILITATION AND INTERFERENCE IN LEARNING ASSEMBLY OPERATIONS

A THESIS

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the Faculty of the Graduate Division

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Robert Bernard O'Connor

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A STUDY OF HABIT FACILITATION AND INTERFERENCE

IN LEARNING ASSEMBLY OPERATIONS

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A STUDY OF HABIT FACILITATION AND INTERFERENCE
IN LEARNING ASSEMBLY OPERATIONS

Robert Bernard O'Connor

ABSTRACT

The purposes of this Thesis were to evaluate the effects of similarity of operation elements, and the effects of level of learning on one operation before learning on another operation is begun.

When a person acquires a new habit, the learning of the new habit may be either aided or hindered by established habits. This situation exists in industry whenever an operator is required to learn a new operation.

The literature survey revealed that very little research had been conducted on this problem on industrial type operations. However, psychologists had conducted a great deal of research on facilitation and interference on learning mental and complex coordination tasks which were similar to the simple coordination learning on industrial operations. Past research has indicated that the similarity of stimuli and responses between two habits is the determining factor in determining if facilitation (positive transfer) or interference (negative transfer or inhibition) will occur.

Inhibition on a new operation was found to increase with the level of learning on the original operation.

In order to determine the effect of similarity of elements, two operations were selected, each of which contained five steps or elements which varied in their similarity to each other. Three of the elements occurred in both operations, but each operation contained two elements not found in the other operation.

Ten student volunteers from undergraduate psychology classes were selected and divided into five groups. One group acted as a control group, working one hour per day for five successive days, on the same operation. Another group spent an hour a day for two days on one operation, performed the other operation for the next two days, and then returned to the original operation for the last day. A third group changed operations every day. The remaining two groups learned the same operations as the second and third groups above, but in the reverse sequence.

Time studies using a split hand stopwatch were used to measure operator performance. From these time studies the average for each operator, for each hour-long session, for each element was plotted on graphs for visual analysis. This was followed by statistical analysis to prove visual observations.

The smallness of the groups, coupled with wide variations between operators, made both visual and statistical analysis difficult. However, graphical and statistical evidence of positive transfer was found in two elements of one operation, although the evidence was not conclusive at an acceptable level of significance. Evidence of inhibition was found in one of the elements which occurred in both operations due to the presence of a nearly identical element in one of the operations. No evidence of differences due to the level of original or interpolated learning was found.

The conclusions reached as a result of this Thesis were that there was strong evidence to suggest that the individual motions involved in learning an element of an operation act as a set of stimuli, and response, and the greater the similarity of the sequence of motions involved in two or more sequences of motions, the greater will be the interference between them, and that positive transfer may be present also in which case the the two effects cancel each other.

CHAPTER I

INTRODUCTION

Industrial engineers do not ordinarily concern themselves with performances during an operator's learning period on an operation. Time studies and methods analysis are usually based on studies of experienced operators. However, the learning period can take up a considerable part of the total time in job shop and small lot size operations. The electric motor control industry is a good example. Each of the manufacturers in the field produce a wide range of sizes and types of motor controls in lot sizes that may vary from one to several thousand. Therefore , knowledge of the learning process would be very useful, not only from the aspect of estimating learning time, but from the standpoint of product design.

The writer of this thesis was introduced to this problem while working as an assembler in the plant of one of the smaller motor control manufacturers, Furnas Electric Company of Batavia, Illinois. One particular department produced a type of manual control for reversible motors known as a "drum controller". Many different models of drum controllers were produced in this same small department in varying lot sizes.

The time that any one operator spent on a particular operation varied from a few minutes to several days. Sometimes one operation would perform several different operations on the same lot. The assistant plant superintendent told this writer that he felt that the employees could produce more if they could work longer on an operation.

The purpose of this thesis shall be to determine what research has been done in the past on problems involving the effect of changing operations on operator performance, and to advance this knowledge by experimentation.

The initial literature survey on this topic revealed that very little had been done on the subject at the industrial level, but that psychologists have done a great deal of research on habit, interference, and facilitation, which is essentially what is involved when an operator changes from one operation to another. When a new habit is learned which is in some way similar to an established habit, interference may result. An example of this occurs when a person changes from carrying his pencils in a certain pocket to carrying them in a different pocket. For a time there is a strong tendency to reach for the pencils where they used to be. However, in time the person becomes accustomed to their new location. However, if he returns them to their old pocket, he will find that he must learn the old habit all over again. The opposite may also occur. If a person injures his hand, which he uses for working, he will find that it is not so difficult to learn to write with the other hand as it was to learn to write in the first place. In this case the old habit has facilitated the development of the new habit.

CHAPTER II

LITERATURE SURVEY

Psychologists have evolved their own terminology for interference and facilitation in learning. Psychologists divide interference into two categories; negative transfer, also known as proactive imhibition. McGeoch states, "Learning to make a new response to an old stimuli yields negative transfer". (1) Retroactive inhibitions is interference in relearning caused by activity between the original learning and the relearning. Habit facilitation is known as positive transfer.

History: One of the earliest mentions of negative transfer was by Thorndike and Woodworth in 1901.

> Improvement in any single mental function need not improve the ability in functions commonly called by the same name. It may injure it. Improvement in any single mental function rarely brings about equal improvement in any other function, no matter how similar ...... (2)

In an experiment on mental learning in 1900 Muller and Pilszecker found evidence of retroactive inhibition. They found that the recall score for a group which had an idle period after learning was much greater than the recall score of a group which had strenuous mental activity in the same period after learning. (3)

Positive transfer was first identified by Weber in 1844. He found that training on an operation using one hand facilitated training using the other hand. (4) In 1924, however, Thorndike concluded that transfer in a general way does not occur at all and that what is regarded as transfer is due to the identical elements in the two jobs under consideration. (5)

In 1932 Viteles mentioned several experiments which tended to disprove the theory that transfer was due to improvement in motor ability through practice. (6) This tends to support the theory of similarity of elements.

McGeoch and McDonald in 1931 concluded that retroactive inhibition increased with the similarity of the original and interpolated task. (7) Wolfe in 1951 stated as a hypothesis, "The greater the similarity between two stimulating situations, the greater should be the similarity between the two responses if habit interference is to be avoided". (8) However, McGeoch stated that interference due to frequent changes of operations usually decreases, and may even disappear with practice. (9)

From the work of these psychologists it may be concluded that similarity of elements is largely responsible for both facilitation and interference, but that their efforts are largely confined to the training period.

Recent Experimentation: There has been very little research in recent years on problems involving facilitation and interference in training on simple manual operations. The experiments have been concerned with difficult mental and motor tasks. (10)

According to Seymour, who conducted a series of experiments on whole versus part learning on turret lathe operations, there is little similarity between motor learning, such as a lathe, and mental learning. (11) However, while the relationships may be different, the fundamentals should be very similar.

There has been considerable research on complex motor operations such as pursuit rotor and target tracking devices. The purpose of much of this research has been to study facilitation and interference to arrive at principles which can be applied to the design of sircraft controls. While they are more complex, they more nearly resemble industrial operations than experiments in mental learning.

In 1952, Kimble, in an experiment using a rotor pursuit transfer which facilitated learning with the other hand.[1] This supports the work of Weber in 1844. (4)

Duncan evaluated transfer in motor learning using two similar tasks on a motor performance testing device and found that positive transfer increased with first task learning and inter-task similarity. He also found no evidence of interference. He attributed the transfer to response generalization and learning how to learn. (13)

McAllister and Lewis used a motor performance testing device to evaluate the effect of level of original learning on facilitation and interference. They found both facilitation and interference at the start of the reversed task and also at the start of the relearning trials, but the effects tended to cancel each other. (14) McAllister concluded that retroactive interference increased as the level of original learning increased, but that the interference effects were reduced with overlearning. (15)

In experiments varying the amount of interpolated learning, McAllister and Lewis found that retroactive interference also increased with the amount of interpolated learning. (15, 16)

Barch and Lewis found that partial reversal of controls on a tracking machine resulted in greater interference than the reversal of both controls. (17)

Other experimenters have other work applicable to this problem. Bilodean and Schlosberg found that the similarity of external stimuli

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[1] "Typical decremental effect to massed practice in general is that it transfers to muscle groups not actually used in the build-up of decrement". (12)

effect retroactive inhibition. Changes in room appearance, lighting and in operation posture reduced interference in learning word lists. (18) Adams found that the slump in output caused by the warm up period at the start of an operation decreased with practice. (19)

Industrial Research: Industry and industrial engineers seem to be only partially aware of the effects of interference and facilitation in Industrial operations. Harrell mentions an assembly operation in which positive transfer was found between training on two different electric switches. He concluded that the identical elements and motions between the two operations, rather than insight into the similar nature of the two processes, was responsible for the transfer. (20) However, it seems doubtful that this work was done as an experiment, but was likely just a measurement of the increased speed of the operators with prior practice on one operation in learning another similar operation.

Barnes stated in 1940 that a large percentage of learning may be the elimination of fumbles and delays rather than build up of speed. He stated that the reduction in fumbles may be seen by plotting the learning curve including fumbles, against a learning curve of the cycle times with the fumbles removed. (21) Fumbles and false motions should be a good measure of interference, but there has been little work on this.

The Need for Further Research: The problem of eliminating interference would be simple if it were always convenient to teach an employee only one operation. However, many companies have such a wide variety of items which are produced in such limited quantities that they must switch employees from one operation to another frequently.

On the basis of past research, there is little interference after the operator becomes skilled. However, while its effects are transitory it is an important problem. Work on this problem may make it possible ultimately to train workers in more jobs to reduce monotony.[2]

Another factor is the need to have someone trained to step into the shoes of a missing worker. To handle that situation, management must train each worker in more than one operation in many cases. At the General Motors foundry at Doraville, Illinois, employees were trained to do several operations since the operations were simple enough to be learned in two or three days. (23)

Lawrence advocated using transfer to reduce the cost of training operators in expensive operations by training them in lower cost operations similar to the expensive one. (24)

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[2] Viteles stated that, "Complete uniformity in manual operations is generally less productive, and leads to greater irregularity in rate of working than a reasonable degree of variety." (22)

CHAPTER III

PURPOSE

There is definitely a need for careful experimentation to evaluate the effects of similarity of elements and level of learning on assembly operation in terms of habit interference and facilitation. Research in this field could lead to the development of principles for use in product design and operator training.

The purpose of this thesis shall be to provide the groundwork for further research in specific phases of this topic by pointing out which areas hold the most promise and to develop methods of attack. It well may be that this thesis will in the end ask more questions than it answers, but in the limited time available the topic cannot be given the intensive treatment it deserves.

Several proven experimental designs have evolved out of the numerous experiments by psychologists on transfer and inhibition. Woodworth in his book on experimental psychology lists five plans. The plan in which a practice group learns one operation, then learns another operation, and finally relearns the original operation is widely used in inhibition experiments. (25) The design used in this experiment will be a variation of this design.

One of the specific objectives of this thesis shall be to observe the effects of element similarity through the study of two operations having three elements in common, and each containing two elements that differ from two elements of the other operation. These elements shall vary in similarity with respect to each other and shall vary in difficulty.

In addition to this, the effect of level of original and interpolated learning will be observed by varying the amount of time spent on one operation before changing to the other. The effects of similarity of elements and level of learning will be evaluated in the light of the theories on positive and negative transfer and retroactive inhibition.

The following hypotheses are proposed for each of the four different elements: there is no significant difference in operator learning due to the presence or absence of prior practice on a similar element and there is no significant difference due to interpolated learning on a similar operation.

A further hypothesis that there is no difference in mean times for a common element owing to the operation in which it is performed is proposed.

CHAPTER IV

EXPERIMENTAL DESIGN

Locale of the Experiment: It would have been very difficult to perform an experiment of this type in an industrial plant. Most firms would be unwilling to permit the disruption of routine necessary to meet the requirements of this thesis. The principal requirements are two operations having elements with varying degrees of similarity: operators without prior practice on these or similar operations, who would be willing to cooperate completely with the experiment, and practice periods of equal length. This experiment was performed at this school using undergraduate students so that these requirements could be met and the variables involved adequately controlled.

The complexity of the operations and the inexperience of the students on manual operations should compensate to some extent for the use of college students in place of factory workers. College students represent a stratified sample considerably above the average factory worker in intelligence, but that does not necessarily presuppose greater dexterity. While college students learn more rapidly habit interference or facilitation should affect the two groups similarly. Motivation of college students is usually greater than industrial workers also.

Selection of the Operations: Two operations were selected which had three elements in common, and two elements which were different from two elements in the other operation. (See Table 1) Both operations used the same parts, but the non-common elements involved putting these parts on the spindle by different methods and in different sequences and positions. (See Figure 1)

The parts used in this experiment are some of the components of the rotor of the Model R44 drum controller manufactured by Furnas Electric Company of Batavia, Illinois. As it is assembled by the Manufacturer, it contains twenty-one parts. Nine of these parts were omitted to reduce the number of elements in the operation, shorten its cycle time and make the rotors easier to disassemble. The cottor pin and the third contact were preassemble to the spindle and third sleeve, respectively, to eliminate the factor of force which would have been required to make those subassemblies.

Length of Practice Session: One hour was chosen as the optimum length of training session because that length was long enough to approximate the situation in industry, yet short enough to allow more students to be used.

OPERATION CHART

TABLE 1

DRUM CONTROLLER ROTOR ASSEMBLY:

OPERATION "A"

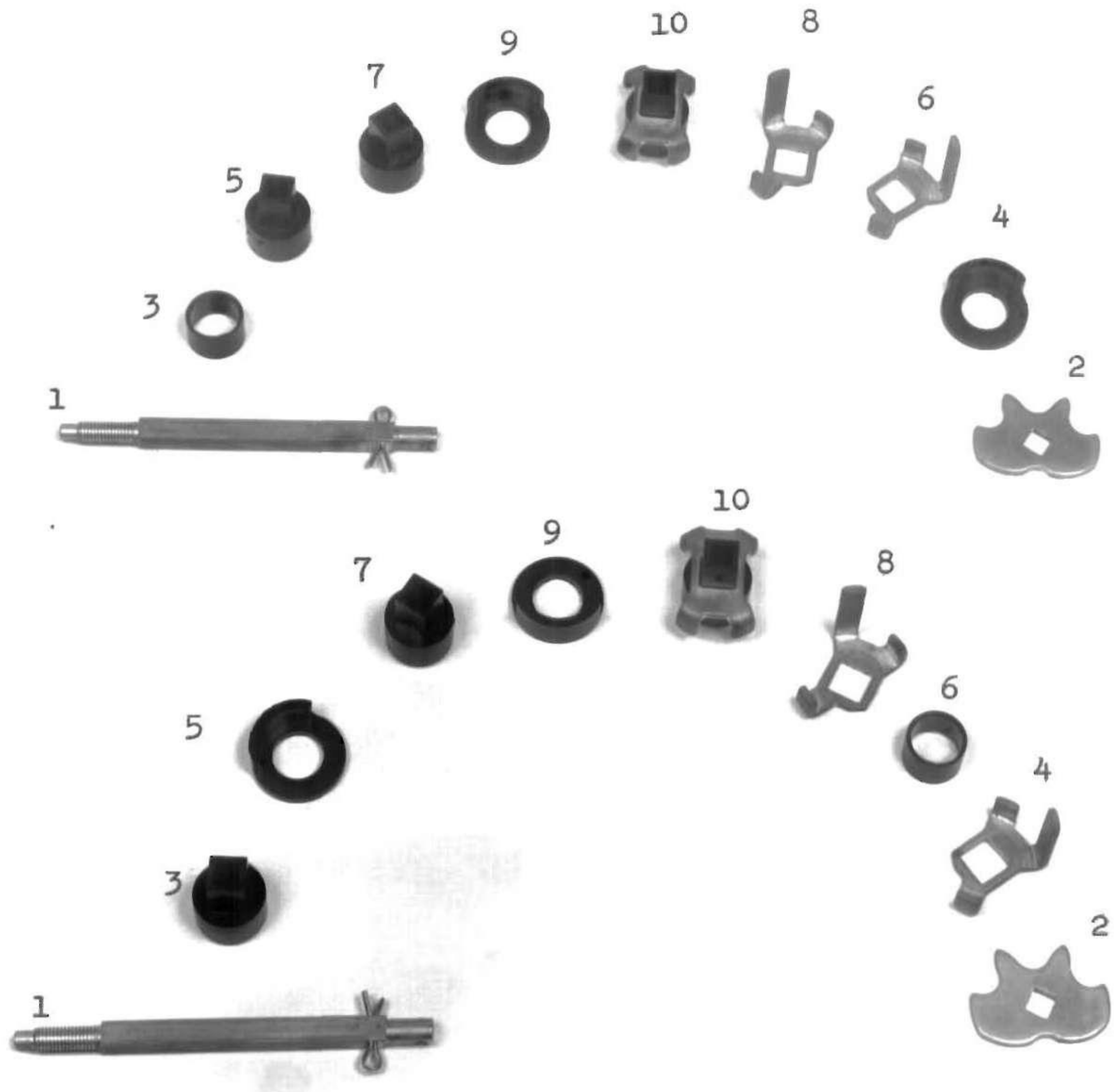
NOTE: Where both hands are indicated as placing parts on spindle simultaneously, left hand always leads. (Part in left-hand placed first)

Activity of LEFT HAND:	TIME	Activity of RIGHT HAND:
Grasp spindle in bin (1)	A	Grasp cam in bin (2)
Transport loaded to fixture (11)	Element 1	Transport Loaded to fixture
Position spindle in fixture with threaded end up and cotter key in slot		Position on spindle with smooth side and cam points facing away and to the left
Reach for tubing (3)		Reach for shield
Grasp tubing in bin (3)	Element 2A	Grasp shield in bin (4)
Transport to spindle		Transport ot spindle
Drop on spindle		Position on spindle with rim up and to the right
Reach for sleeve (5)		Reach for 1st contact (6)
Grasp sleeve in bin (5)	Element 3A	Grasp contact in bin (6)
Transport to contact		Transport to sleeve
Hold sleeve		Position contact on sleeve with points down over large end of sleeve
Transport contact assembly to spindle		Assist left hand
Position on spindle with small end of sleeve inserted into shield and tubing and with long contact points away from operator and to the left		Lift tubing and shield slightly to aid left hand
Reach for sleeve (7)		Reach for 2nd contact (8)
Grasp sleeve (7)	Element 4	Grasp contact (8)
Transport to spindle		Transport to spindle
Position sleeve on spindle with large end down		Position 2nd contact on sleeve with points down and long point to the right and toward the operator
Reach for shield (9)		Reach for contact assembly (10)

TABLE 1
(continued)

Grasp shield in bin (9)	Grasp contact assembly (10)
Transport to spindle	Transport to spindle
Position on spindle with rim down over contact	Position on spindle with contact points alligned with points on other contacts
Grasp top of spindle, transport spindle assembly to tote pan and release (12)	Reach for counter (13) Grasp and click counter
Reach for spindle (1)	Reach for cam (2)
OPERATION "B"	
Grasp spindle in bin (1)	Grasp cam in bin (2)
Transport loaded to fixture	Transport loaded to fixture
Position spindle in fixture with threaded end up and cotter key in slot	Position on spindle with smooth side up and cam points facing left and away from operator
Reach for sleeve in bin (3)	Reach for 1st contact (4)
Grasp sleeve (3)	Grasp 1st contact
Transport sleeve to spindle	Transport contact to spindle
Position sleeve on spindle with large end down	Position contact on sleeve with points up and long point to the left and away from operator
Reach for shield (5)	Reach for tubing (6)
Grasp shield in bin (5)	Grasp tubing in bin (6)
Transport shield to spindle	Transport tubing to spindle
Position shield on spindle with rim down over contact	Drop tubing on spindle
Reach for sleeve (7)	Reach for 2nd contact (8)
Elements 4 and 5, same as in A above	

Operation A



Operation B

(Numbers indicate sequence in which parts are used)

Fig. 1 - Parts Used in the Experiment

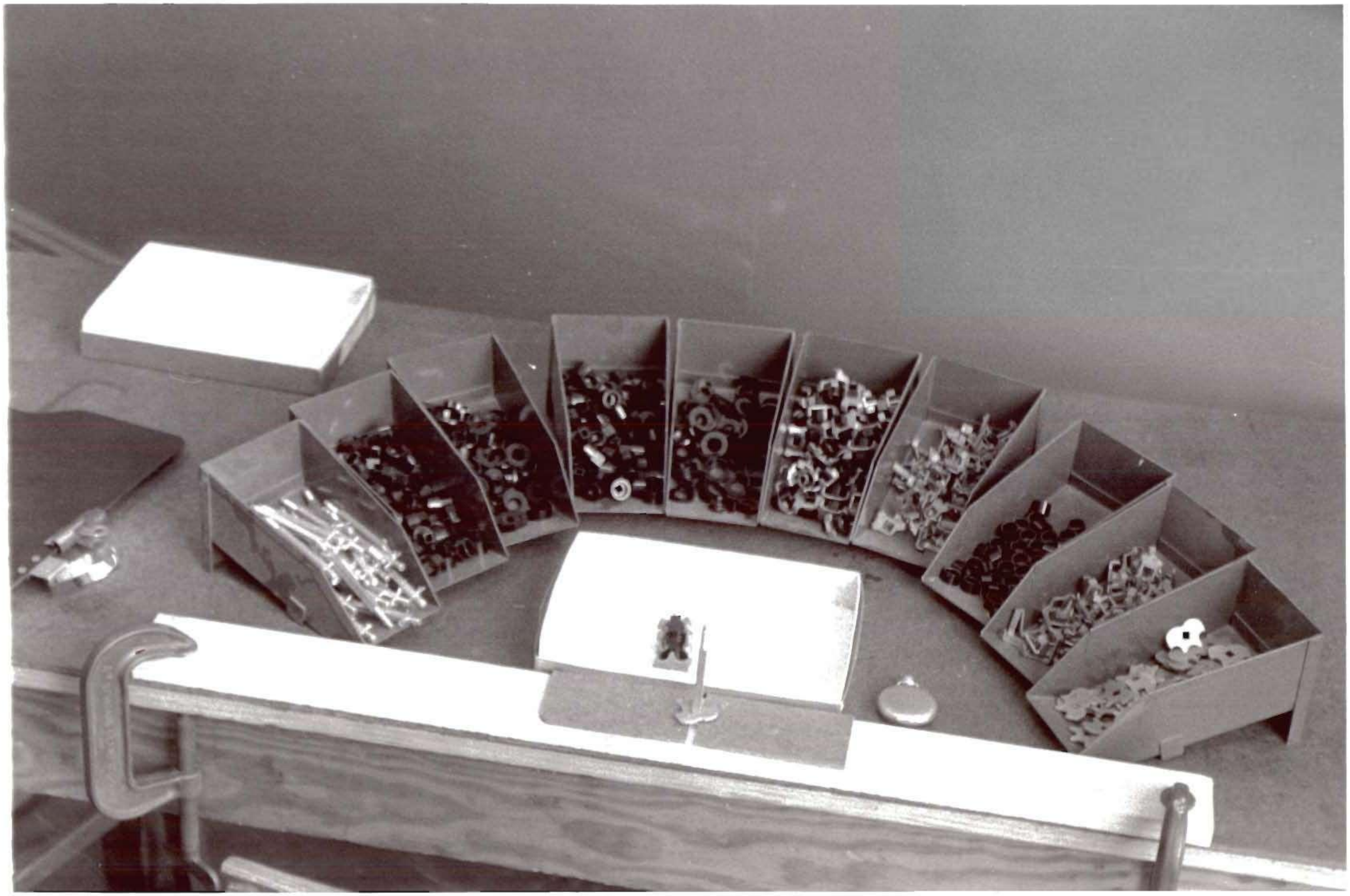


Fig. 2 Workplace Layout (*For This Photo Counter Simulated by Stopwatch)

Five sessions were chosen as a good total length of practice. It was felt that the learning curves of the operators would have leveled off sufficiently by that time to make further study unnecessary. The use of five sessions facilitated the study of the effect of level of learning on habit interference and facilitation. Five sessions could be easily divided to provide two levels of learning, one hour alternation and two hour alternation. In addition to these, a control group was used with one operation to study the learning which would take place if no conflicting operation was learned. This may be visualized better from the chart below:

TABLE 2

Group	Individual	Session 1	2	3	4	5
A - C (Opn A Control)	1	Opn A	Opn A	A	A	A
	2	A	A	A	A	A
A - 2 (Starts with A)	1	A	A	B	B	A
	2	A	A	B	B	A
A - 1	1	A	B	A	B	A
	2	A	B	A	B	A
B - 2	1	B	B	A	A	B
	2	B	B	A	A	B
B - 1	1	B	A	B	A	B
	2	B	A	B	A	B

The time required to conduct this experiment prohibited the use of more than two operators in each group. The two groups, starting with operation B were used to find if there was any effect due to the sequence in which the operations were learned, and to evaluate positive transfer from operation B to operation A.

Method of Collecting Data: Analysis of element times was chosen as the method of evaluating operator performance. In order to obtain a representative sample of operator performance and measure the operator's progress within each session, three separate time studies were taken, one at the beginning of the hour long session, one after thirty minutes had elapsed, and one immediately before the end of the session. Each of these studies was based on approximately ten cycles.[3]

The following methods of obtaining time data were considered: motion pictures, kymograph, marstochron and the split hand stopwatch. The use of motion pictures was rejected since it would take a very large amount of film to record all of the necessary studies. The school's kymograph was unsatisfactory since it had a tape speed of 300 inches per minute necessitating the use and analysis of approximately 18,000 feet of tape. The kymograph's accuracy would have been unnecessarily large considering the fact that the individual operators were expected to have a high range of element times. The marstachron, which has a tape speed of 10 inches per minute, which may be read to an accuracy of .002 minutes, would have been useful in this experiment, but was unavailable at the time the experiment was started.

Since the elements were long enough for ordinary stopwatch techniques, and since the variance of the element times was large, the split hand stopwatch was chosen as the timing device for this experiment. This introduced the factor of errors in reading the stopwatch complicated by the writer's inexperience in taking time studies. However, the writer felt that the use of the stopwatch was justified in this experiment.

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[3] Frequently one ot more readings were missed resulting in many of the studies being based on only eight or nine readings for each element.

CHAPTER V

PROCEDURE

Sufficient parts to make 50 complete rotor assemblies were borrowed from the manufacturer, Furnas Electric Company, for use in this experiment and returned upon completion of the experiment.

Student colunteers were obtained from sections of an undergraduate psychology course, Psychology 401. The general topic of the thesis was presented to the class and interested students were given schedule blanks to fill out and turn in to their instructor, Dr. Joseph Moore. From these schedules a master schedule was drawn up allowing one and one-half hours for each session to provide time for briefing and possible late arrival. The sessions did not usually last longer than sixty-five minutes, and in the latter part of the experiment students were scheduled with less leeway than this. (See schedule in Appendix) Each student was scheduled so that his part of the experiment fell on approximately the same time of day for five consecutive days.

The part of the experiment involving persons starting with operation A were scheduled so as to randomize the sequence in which the individuals were used in order to minimize any effect due to the writer's progress in learning to conduct the experiment and other variations that might occur due to the passage of time, such as, wear on the parts and changes in procedure caused by the writer himself becoming more familiar with the techniques of assembling the parts.

Environment: The thesis experiment was conducted in a small room in the Industrial Engineering Building, equipped with desk calculators for use by graduate students. The equipment for this experiment consisted of a large table, two wooden chairs, ten small parts bins, two stationery boxes for use as tote pans, a simple fixture secured to the table with two C clamps, a hand actuated counter, and a split hand stopwatch, and the time study clipboard. The fixture consisted of a long, narrow board with a hole for the end of the spindle and two pieces of masonite nailed one on either side of the hole to form a slot for the cotter key, so that the spindle could not rotate in the hole. The table was pulled out from the wall at one end so that the finished assemblies could be disassembled and returned to the proper bins for reuse without interfering with the operators.

While the lighting was satisfactory throughout the experiment, heating and ventilation were a problem. The temperature varied from day to day, and was frequently fairly high. The door was left open on those days to provide ventilation. While the temperature was not measured, a notation of the temperature range, that is, hot, mild or cool, was recorded on the time study sheet.

Distractions in the form of persons coming into the room and using the desk calculators occurred several times, and were noted on the time study form.

The noise level in the room also varied with the amount of activity going on outside the room. This was impossible to control since it was necessary to perform the experiment both on quiet Sundays and on weekday mornings when students, going to class, amde a great deal of noise.

Conduct of the Experiment: Each student was briefed at the beginning of his first session. He was shoen a complete R44 rotor and was told a little about its manufacture. The proceedure that would be used throughout his part of the experiment was also explained at that time.

The training method used in instructing the student in performing the operation was similar to the usual training method in industry. The writer assembled one rotor slowly explaining each step in the operation. Next the writer would slowly assemble another rotor, this time emphasizing only a few key points. The student volunteer would then make two rotors slowly so that he would be familiar with all the elements of the operation before the hour long session began. The same training procedure was followed at the beginning of each of the five sessions for each operator.

As soon as the operator completed his two practice assemblies, he was told to begin working at his normal pace. Three sets of time studies were taken during the hour, the first ten cycles, ten cycles after thirty minutes had elapsed and ten more in the last five minutes of the hour. During the intervals in which time studies were not being taken, the writer disassembled the rotors which the operator had completed in order to keep the operator well supplied with parts. There were not enough parts available to last the entire hour.

The student depressed a small hand counter which registered the number of units he produced. This step was included in the last element of the operation. The counter was read at five minute intervals by the writer, and the readings were recorded on the time study sheet.

Conversation between the operators and the writer was permitted during the course of the experiment. Its extent varied between the different students, since some were more talkative than others. The conversation served to keep the atmosphere more relaxed and informal.

The four elements which occurred in only one operation were analyzed using analysis of variance techniques. Three variables were involved in each of these elements, the amount of practice on that element, the group and the operators. The first two were fixed variables, and the third was random. The variable of operators was nested in groups, that is, each operator was in only one group. There were only two possible interactions, between groups and practice, and between operators and practice. The first two hours of practice on that element and the four groups, each containing two operators, were involved in the analysis. The mean squares of the practice and group-practice interaction were tested against the operator-practice interaction. The group mean squares were tested against the operator mean squares. The resulting F ratios were compared with tables of F values to determine the levels at which the variances were significant, if any.

In order to determine the effect of the operation in which they were performed on the common elements, the following procedure was used. The session means for the element under consideration for the second hour were subtracted from the means for the first hour, the means for the third hour were subtracted from these for the second hour, and so on, for the five hours of practice. These numbers were coded by adding 100 to them to eliminate negative numbers. The numbers were classified into four groups according to the sequence of operations involved. The four groups were, operation A to operation A, operation A to B, B to B, and B to A.

In order to obtain balanced designs for analysis of variance, two block designs were used. The second to third and fourth to fifth hour columns involved only two sequences of operations, A to B and B to A with four subtracted figures in each box. All four of the above groups were involved in the analysis of the first to second and third to fourth columns.

The effect of operators was not considered as a separate variable. The data was considered as being samples of two or four, depending on the size of the group, from the universe of operators. This was called the within boxes variance which included other factors, such as the operator-practice interaction.

The mean squares of the groups, practice columns, and group and practice interactions, were tested for significance against the within boxes mean squares.

The student was permitted to know how much he was producing, and in general terms, how that compared with others. Usually this information was given in response to questions by the student. No specific information as to the specific objectives of the experiment was given until the conclusion of the fifth session. At that time, the student was shown some of the learning curves that were available.

Method of analysis: The element means ($\overline{x}$) for each of the three time studies in each session were pooled to obtain an element mean for the entire session ($\overline{\overline{x}}$). The range between the highest $\overline{x}$, and the lowest $\overline{x}$, was calculated as a measure of the operator's progress within the session. This range was designated $R_{\overline{x}}$.

The session $\overline{\overline{x}}_a$ and $R_{\overline{x}}$ were plotted on graphs and analyzed for visual evidence of differences in level of performance or in trends from session to session. Evidence found by visual analysis was then evaluated statistically.

CHAPTER VI

DISCUSSION OF RESULTS

General Comments: The student volunteers, who acted as operators in this experiment were very cooperative, and with one possible exception, gave every indication of trying to perform at a constant rate of effort. However, there were large differences in effort between operators. The operators were asked to perform at a steady pace and one that would be natural for them, but several operators gave evidence of being strongly motivated to produce as many units as possible in one hour.

Operator comments brought out several defects in the experiment. The chair used in this experiment was a common wooden chair not designed for factory-type work. The operators complained that it was not the correct height for comfort. While the operator's complained of fatigue, since they were not used to repetitive manual work, analysis of the counter readings reveal no appreciable slumps that could be credited to fatigue.

The operators also complained that the third element in operation A was very difficult. They felt that it would have been easier to hold the contact in the left hand and insert the sleeve into it with the right hand rather than to hold the sleeve in the left hand and fit the contact over it with the other hand.

Analysis of the Four Elements Found in Only One Operation: The second element in operation A was the simplest of all the elements in the two operations, consisting of placing a small piece of tubing and a plastic "contact shield" on the spindle. (see Table 1) As a result, it had the shortest element time. The times frequently fell in the range in which the accurracy of stopwatch time study is questionable, .03 to .05 minutes. The short element time also increased the effect that motivation differences and methods changes could have on the results. The simplicity of this element resulted in its being learned very rapidly with very little progress being made after the second hour. (see Table 2)

TABLE 3
Session Means ($\bar{\bar{X}}$)
ELEMENT 2A

Group	Individual	Hour 1	2	3	4	5
A C	1	.073	.047	.045	.037	.039
	2	.067	.050	.050	.042	.040
A 2	1	.055	.044	--[1]	--[1]	.033
	2	.050	.046	--[1]	--[1]	.052[2]
A 1	1	.072	--[1]	.045	--[1]	.040
	2	.046	--[1]	.030	--[1]	.033
B 2	1	--[1]	--[1]	.044	.035	--[1]
	2	--[1]	--[1]	.046	.047	--[1]
B 1	1	--[1]	.041	--[1]	.034	--[1]
	2	--[1]	.039	--[1]	.036	--[1]

---

1 Operation B performed during this session

2 Poorly motivated operator

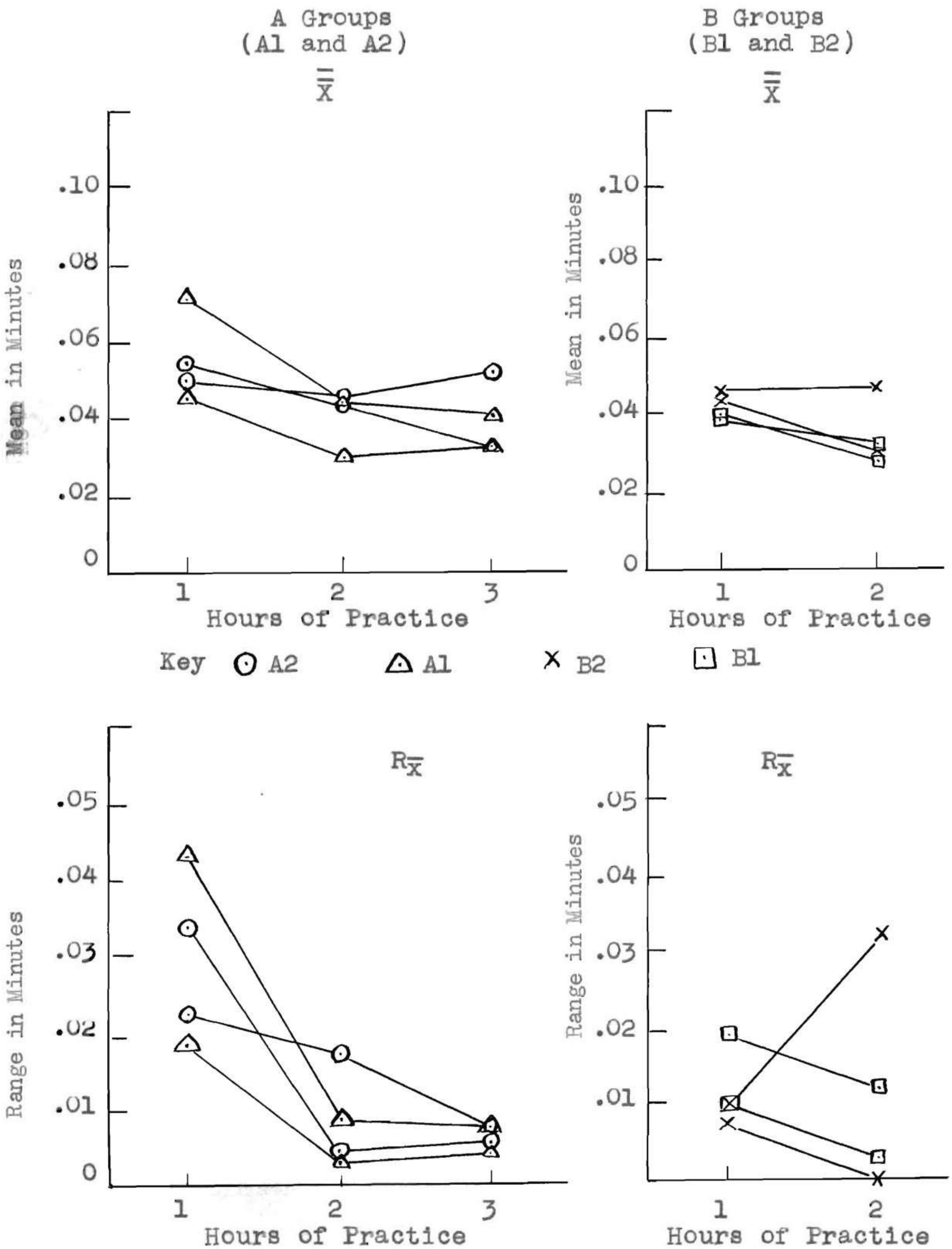

Fig. 3 - Learning Curves for Element 2A

Visual analysis of the figures in table 2 and of the curves on Figure 4, reveal a wide variation between operations, particularly during the first hour. However, those who started with operation A generally appear to have higher mean element times than the B group. This was what one would expect if experience on operation B were facilitating the learning of this operation. The first and second hours of practice appear to approximate the second and third hours of practice of the A groups.

TABLE 4

Analysis of Variance for the First Two Hours of Practice on Element 2A:

Source of Variance	Sum of Squares	Degree of Freedom	Mean Squares	F Ratio	Level of Significance
Hours of Practice	361	1	361	20.	.025
Groups	333	3	111	.94	No
AvsB 272		1	272	2.22	NO
1vs2 36		1	36	.306	No
— 25		1	25	.212	No
Groups and Practice	199	3	66	3.66	No
Alteraction		1	100	5.55	.10
AvsB 100		1	56	3.66	No
1vs2 56		1	42	2.33	No
— 42					
Operators	472	4	118	—	—
Operators and Practice Interaction	71	4	18	—	—
Total	1436	15			

This statistical analysis revealed only two significant findings. The significant difference between hours of practice is natural and of little consequence in this experiment, since an operator would naturally be expected to do better on an operation the second time he did it than he did on his first hour of practice. The significant difference between the A and B groups on the group and practice interaction is of more interest. However, this is only significant at the .10 level. The largest source of variance is between the A groups and B groups in the group effects, but this is not significant at any acceptable level. The null hypothesis that there is no significant difference in learning characteristics between the groups cannot be refuted in spite of considerable visual and statistical evidence to the contrary.

The main reason for the inconclusive results in the group test is the large variance of the operators against which the group effects were tested.

One of the principal characteristics of learning curves of the type involved in this experiment is that the slopes of the curves progressively decrease. The interaction between groups and practice indicates that the B groups have significantly flatter learning curves for their first two hours. This tends to confirm the idea that practice transfer caused the first and second hours of practice of the B groups to assume the characteristics of the second and third hours of the A groups.

The third element in operation A was the most difficult element in the experiment. It had very little similarity to any other operation since the contact and the sleeve were fitted together in the air and then placed on the spindle rather than being assembled on the spindle as in all the other elements. The difficult parts of the element were fitting the contact over the sleeve, and inserting the small end of the sleeve into the shield and tubing on the spindle.

This element had the largest element time, the lowest session mean being .089 minutes with most of the session means being around .120 minutes or above. Therefore, this element would be the least likely to be effected by time study errors.

TABLE 5

Session Means $\bar{\bar{x}}$ for Element 3A:

Group	Individual	Hour	1	2	3	4	5
AC	1		.185	.113	.094	.089	.093
	2		234	.153	.131	.120	.113
A2	1		179	.146	—	—	.131
	2		251	.168	—	—	.139
A1	1		226	—	.157	—	.128
	2		135	—	.107	—	.090
B2	1		—	—	.134	.116	—
	2		—	—	.144	.132	—
B1	1		—	.157		.125	—
	2		—	.134		.126	—

Here again the performance of the B groups resemble the second and third hours of practice of the A groups in session means ($\bar{\bar{x}}$) range within the session ($R_{\bar{x}}$) and trends from one session to the other.

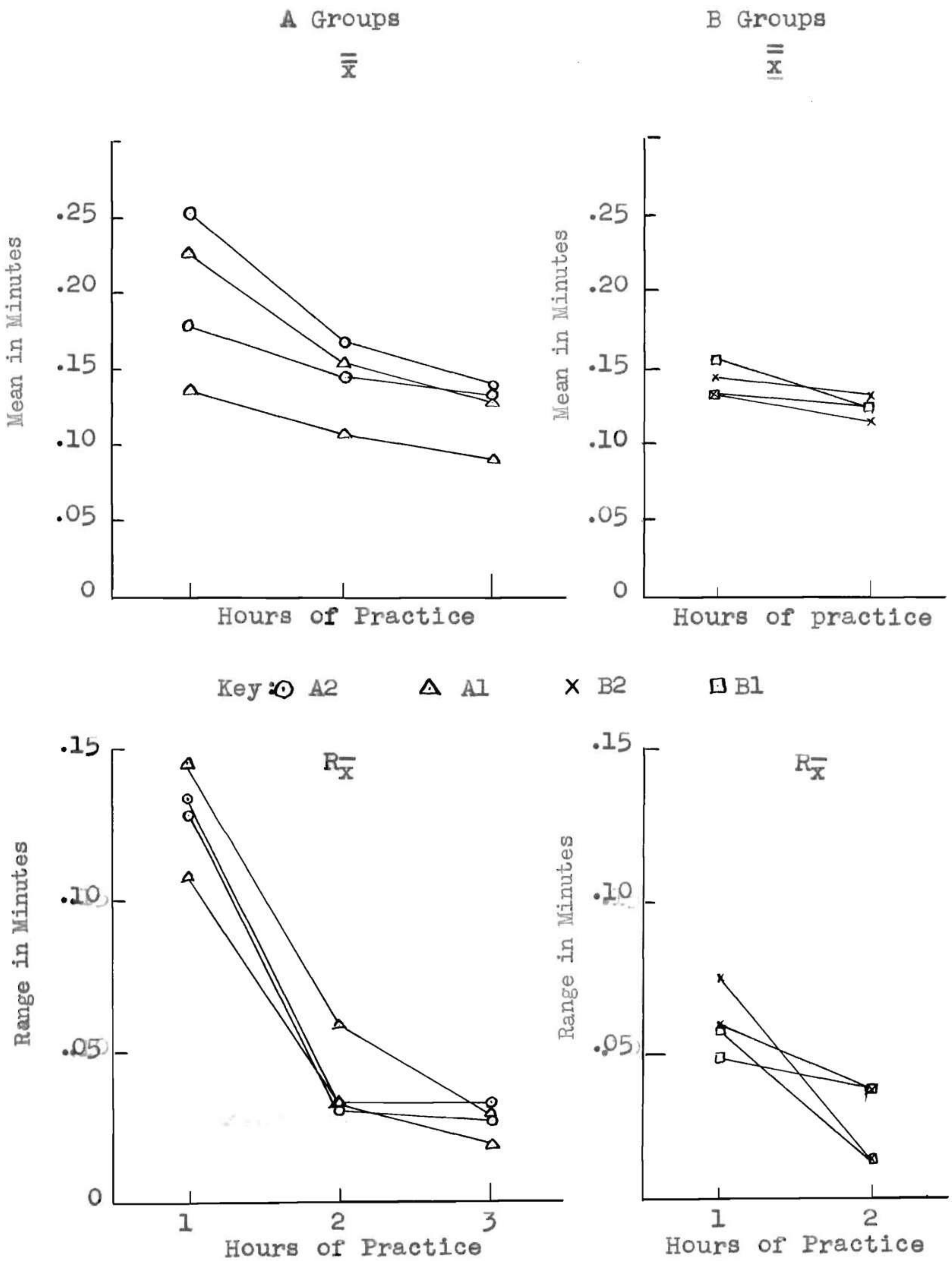

Fig. 4 - Learning Curves for Element 3A

TABLE 6

Analysis of Variance for Element 3A:

Source of Variance	Sum of Hours	Degrees of Freedom	Mean Squares	F Ratio	Level of Significance
Practice	5113	1	5113	17.51	.025
Group	7443	3	2481	1.369	No
A vs B 5550		1		3.06	No
1 vs 2 703		1		.387	No
— 1190		1		.655	No
Practice and Group	1376	3	459	1.476	No
A vs B 1332		1		4.315	No
1 vs 2 2		1		—	No
— 42		1		.132	No
Operators	7260	4	1815	—	—
Operators and Practice	1167	4	292	—	—
Total	22434	15			

As in element 2A there was a significant difference between the first and second hours of practice which was to be expected.

The results of this analysis are very much similar to the results of the analysis on element 2A. The variance of the operators obscured any conclusive evidence of difference in means between the groups, but the largest source of variance between groups is between the A groups and the B groups, and there is a nearly significant difference in interaction between groups and practice. Therefore, the null hypothesis must be accepted.

The second element in operation B used the same parts as were used in element 3A. However, they were placed on the spindle by approximately the same methods as were used in element 4, which was common to

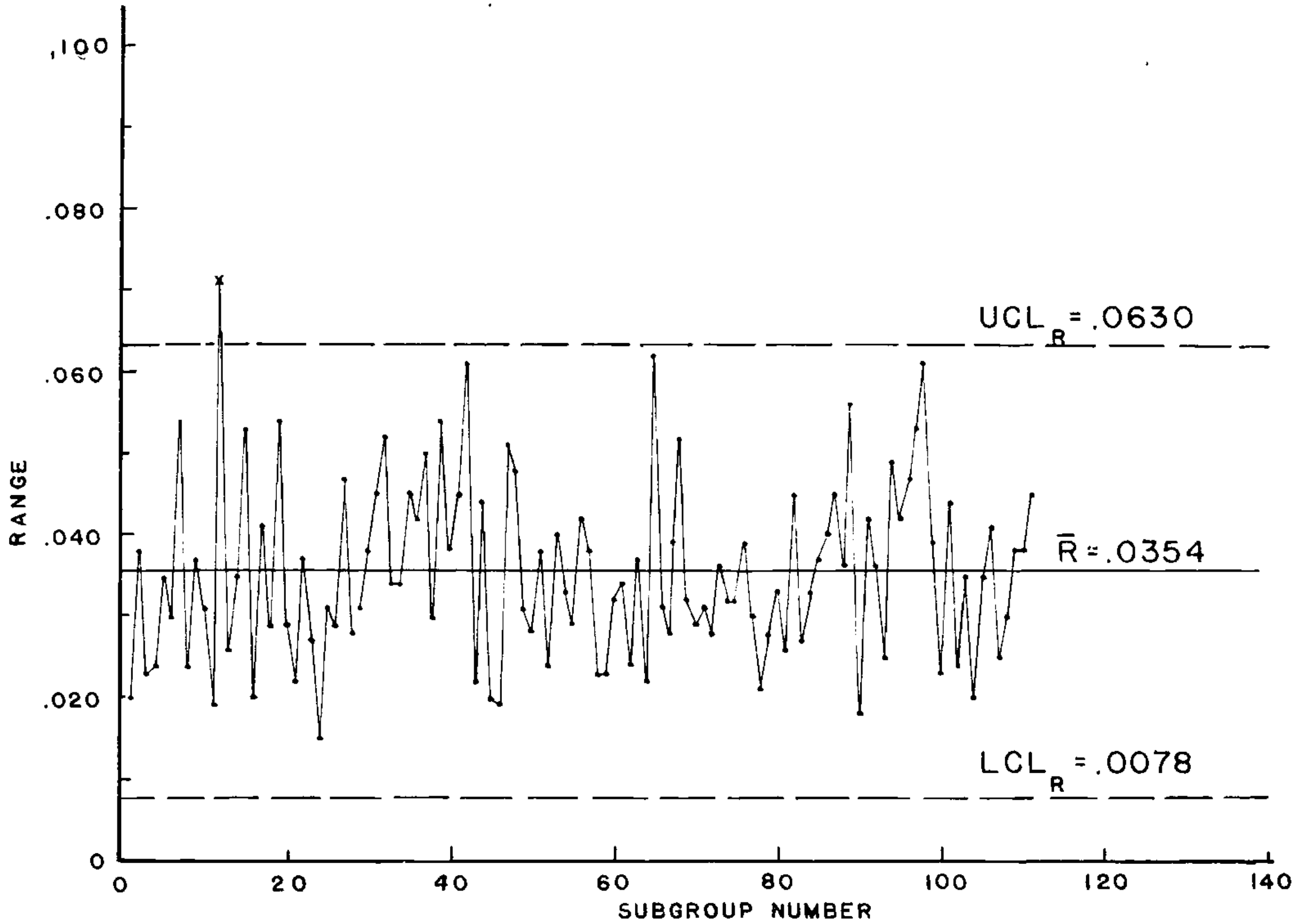

Figure 9. R-chart — Phase 2

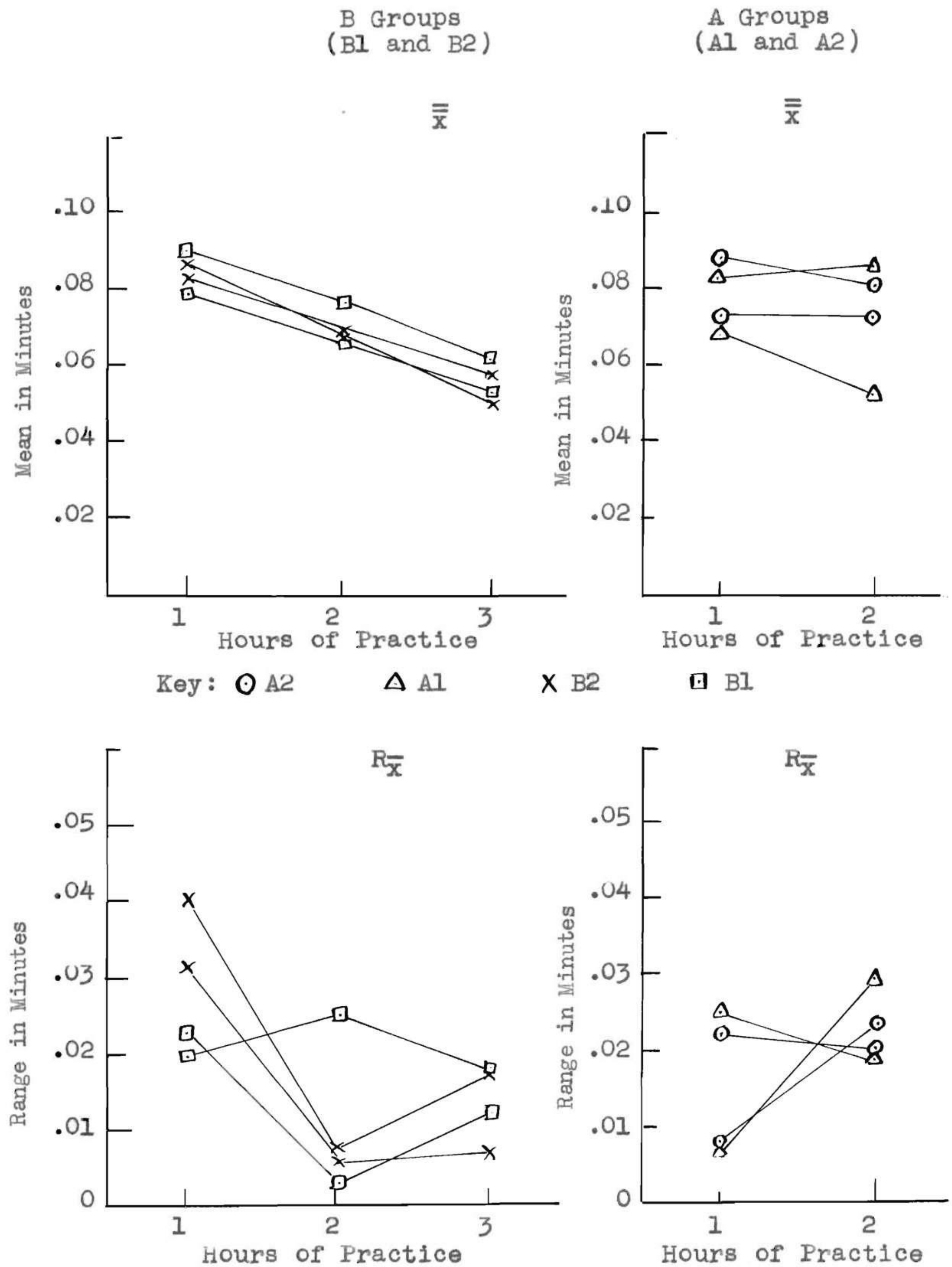

Fig. 5 - Learning Curves for Element 2B

TABLE 8

Analysis of Variance for Element 2B $\bar{\bar{x}}$ s:

Source of Variance	Sum of Squares	Degrees of Freedom	Estimated Variance	F Ratio	Significance Level
Practice	990	1	390	15.6	.025
Groups	91	3	30	.147	No
A vs B 10.5		1	10.5	.051	No
1 vs 2 28.		1	28	.137	No
-- 52.5		1	52.5	.256	No
Group & Practice 113	113	3	38	1.52	No
A vs B 105		1	105	4.195	No
1 vs 2 0		1	0	-	No
-- 8		1	8	.320	No
Operators	821	4	205	-	---
Operators & Practice	99	4	25	-	---
	1514	15			

Again the null hypothesis must be accepted. There is no evidence of any difference bewteen the means of the groups, but the largest part of the groups and practice interaction is between the A groups and the B groups. However, this difference does not even quite reach the .10 level.

While in the two preceeding analyses, the groups effect was nearly the same as the operator effect, in this analysis the group effect is very small in comparison. It is so small, in fact, that individual differences cannot be blamed for obscuring evidence of group differences. There is evidence, graphical or statistical, of a difference in session means between the two groups, and therefore, there is no evidence of positive transfer. Some transfer may exist, but if it

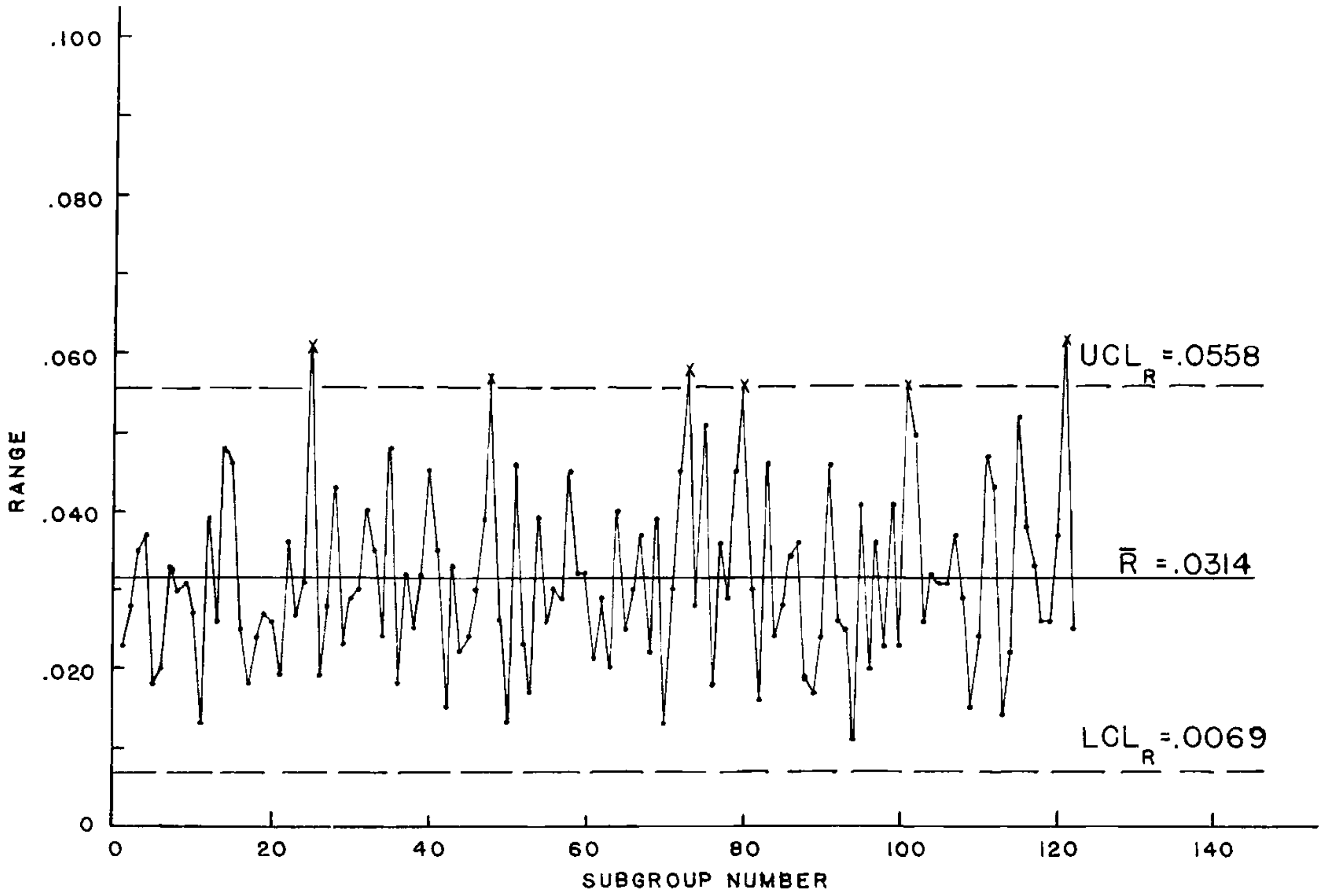

Figure 11. R-chart — Phase 3

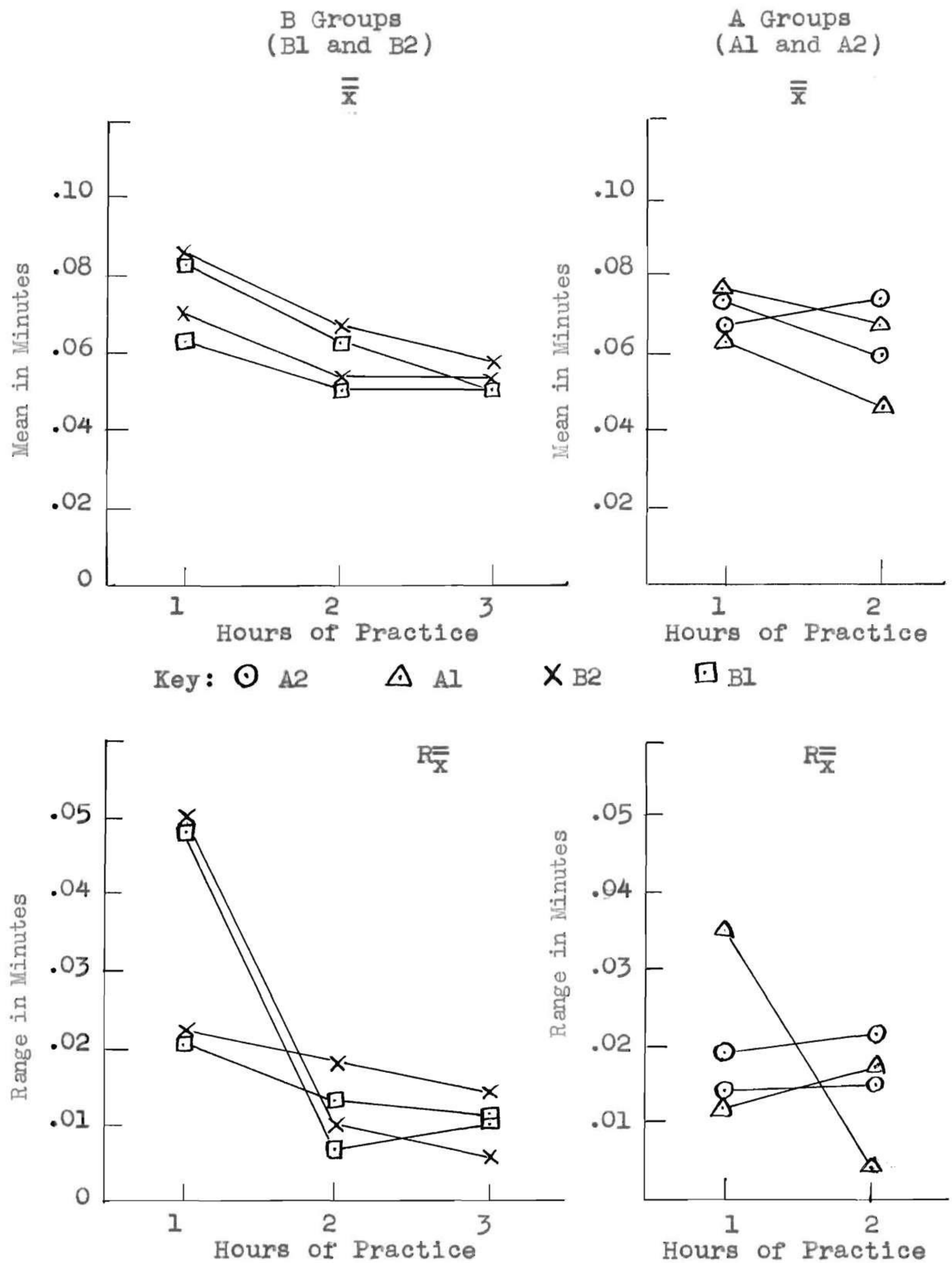

Fig. 6 - Learning Curves for Element 3B

TABLE 10
(continued)

Source of Variance	Sum of Squares	Degrees of Freedom	Mean Squares	F Ratio	Significance Level
Practice & Groups	125		42	1.099	No
A vs B	64	1	64	1.60	No
1 vs 2	25	1	25	.625	No
—	36	1	36	.900	No
Operators	795	4	199	—	—
Operators & Practice	159	4	40	—	—
	1858	15			

As in 2B, there was no evidence, either visual or statistical, of any difference in level of performance or in the effect of practice (the group-practice interaction). Therefore, the null hypothesis must be accepted again.

Some positive transfer could logically be expected to take place since these last two elements were similar to some of the other elements in the two operations. Although nothing can be proven, this may be evidence of inhibition.

The Three Common Elements: As was mentioned before, element 4 was very similar to element 2B. From a visual analysis of this element it appears that element 2B caused some inhibition in learning the common element 4. The operators seem to have higher element times for element 4 when performing operation B than when performing operation A, in which there was no element as similar to 4 as 2B was. (See Table 10 and Figure 7)

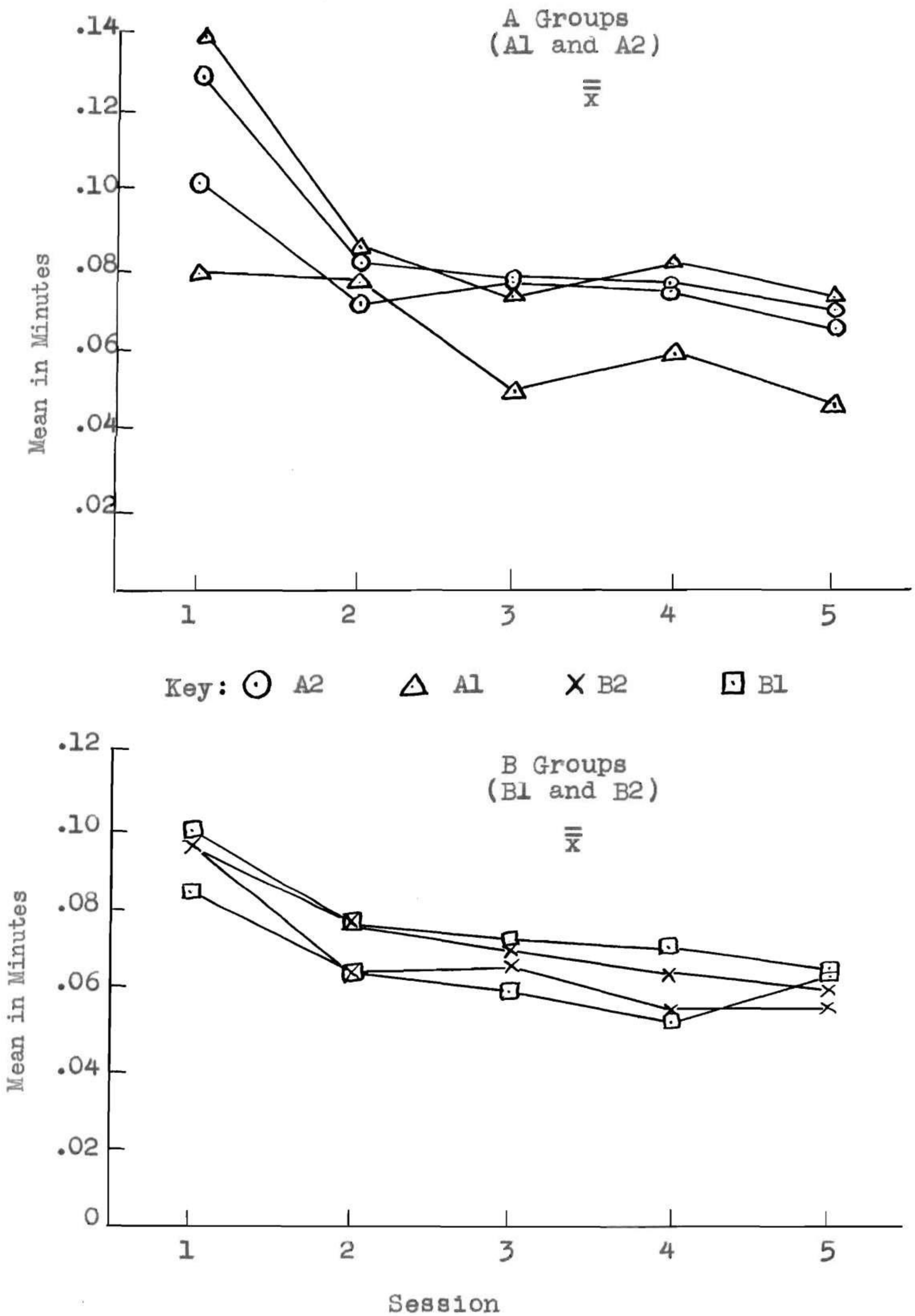

Fig. 7 - Learning Curves for Element 4

TABLE 11

Element Means ($\bar{\bar{x}}$) for Element 4:

Group	Individual	Hour 1	2	3	4	5
AC	1	A.093	A.068	A.054	A.058	A.054
	2	A.107	A.083	A.067	A.061	A.060
A2	1	A.102	A.071	B.076	B.075	A.065
	2	A.129	A.082	B.077	B.077	A.070
A1	1	A.139	B.086	A.075	B.082	A.073
	2	A.079	B.077	A.049	B.060	A.046
B2	1	B.095	B.014	A.066	A.054	B.055
	2	B.096	B.076	A.069	A.063	B.060
B1	1	B.099	A.076	B.071	A.070	B.064
	2	B.084	A.063	B.059	A.052-	B.063

TABLE 12

Analysis of Variance for Element 4; Test of Operator Progress for the 1st ot 2nd and 3rd to 4th Hours of Practice:

Source of Variance	Amount of Variance	Degrees of Freedom	Mean Squares	F Ratio	Significance Level
Practice	2997	1	2997	9.525	.025
Group	487	3	162	.515	No
Group & Practice Interaction	204	3	62	.194	No
Within Boxes	2516	8	315	---	---
	6204	15			

Test of Operator Progress from the 2nd to 3rd and 4th to 5th Hours of Practice:

Source of Variance	Amount of Variance	Degrees of Freedom	Mean Squares	F Ratio	Significance Level
Practice	16	1	16	.262	No
Group	381	1	381	6.250	.05
Group & Practice Interaction	104	1	104	1.705	No
Within Boxes	735	12	61	---	---
	1236	15			

Statistical analysis of the fourth element revealed that there was a significant difference between groups when the operators' progress between the second and third and fourth and fifth hours were considered. This difference was significant at the .05 level, and almost reached the .025 level. Analysis of the first and second, and third and fourth hours revealed no significant findings. However, the evidence is strong enough to reject the hypothesis that there is no difference in mean times for this element, owing to the operation in which the element was performed.

There was no evidence of any difference between groups or operations for the other two elements that were common to both operations. Both of them were different from the other elements involved in the experiment. There was no evidence of differences between groups that could be credited to the sequence in which the groups were used.

None of the elements showed any evidence that could have been due to the level of original or interpolated learning.

While psychologists hold that similarity of stimulus and besponse is the cause of facilitation and inhibition, little is known about what constitutes similarity, or when positive transfer ends and inhibition begins.

Breaking the elements into their fundamental motions, and comparing them therblig by therblig may give some meaning to the results. The answer may lie in comparing the sequence of therbligs with the sequences in similar elements. Each therblig, or sequence of therbligs, may act as a stimulus to which the following therblig is the response.

However, a following therblig, or sequence, may result in backward conditioning in which case a therblig, or sequence, could influence a preseeding therblig. A limitation to such a concept is the fact that it is difficult, if not impossible, to say when a therblig begins or ends, and two therbligs may occur simultaneously such as when a person positions a pencil in his hand as he transports it to the paper.

The transport and grasp therbligs in elements 2B, 3B and 5 are nearly identical in length of travel and shape of the objects being grasped. Learning to handle the parts and familiarity with the sequence in which each element began by going to the next bin would be likely to cause positive transfer.

The therbligs in which inhibition would be most likely to cause interference are position and assemble. The simplicity of positioning, consisting of a simple dropping of the parts on the spindle probably accounted for the lack of inhibition in 2A. Element 5 also contained little positioning in relation to its total time since it was a catch-all element containing several steps not found in any other element. As a result, its entire sequence was different although it started out the same. Interference was either practically nonexistant, or the correction of it of such short duration, that evidence of it was practically nil. On the other hand positioning took up a considerable part of element 3B, even though it was fairly simple. No evidence of inhibition was apparent, but neither was there any trace of positive transfer. It must be concluded therefore, that if they were present they obscured each other. (See Table 12)

TABLE 13

Comparison of Therbligs in Elements 2A, 3B, and 5:

L. H.			Therblig	R. H.		
2A	3B	5		2A	3B	5
Tubing	Shield	Shield	(a) Grasp	Shield	Tubing	Contact #3
To spindle	To spindle	To spindle	(b) Transport Loaded	To spindle	To spindle	To spindle
Hold by sides	Hold by edge w. rim away from palm	Hold by edge w. rim away from palm	(c) Position	Hold by edge w. rim toward palm	Hold by sides	Hold by rim w. points away from palm
Drop on spindle	Place with rim down & to right	Place with rim down & to left	(d) Assemble and Release	Drop with rim up & to the left	Drop on spindle	Place on square spindle with points down
*	*	To top of spindle	(e) Transport empty	*	*	To counter
*	*	Grasp spindle	(f) Grasp	*	*	Grasp counter
*	*	T L to tote pan	(g) ---	*	*	depress counter
*	*	Release spindle	(h) Release load	*	*	Release counter
to bin 5	to bin 7	to bin 1	(i) Transport Empty	to bin 6	to bin 8	to bin 2

The parts involved in elements 3A, 2B, and 4 are identical for all practical purposes. The contacts are difficult to grasp, and position

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* No corresponding therblig in this element.

owing to their irregular shape so that familiarity in handling them might be expected to yield positive transfer.

TABLE 14

Comparison of Therbligs in Elements 3A, 2B, and 4:

L. H. 3A	L. H. 2B	L. H. 4	Therbligs	R. H. 3A	R. H. 2B	R. H. 4
Sleeve	Sleeve	Sleeve	(a) Grasp	Contact	Contact	Contact
To contact	To Spindle	To Spindle	(b) Transport Loaded	To sleeve	To spindle	To spindle
Hold by long end	Hold by small end	Hold by small end	(c) Position	Points away from palm	Points toward palm	Points away from palm
Fit together in air	Drop on square spindle	Drop on square spindle	(d) Assemble and release	Fit together in air	Fit on sleeve points up	Fit on sleeve points down
T L to spindle	*	*	(e) Transport	T E to spindle	*	*
Insert small end of sleeve into tubing & shield	*	*	(f) Position & assemble & release	Align tubing & shield with spindle	*	*
T E to bin 7	T E to bin 5	T E to bin 9	(g) Transport empty & search	T E to bin 9	T E to bin 6	T E to bin 5

However, the sequence of therbligs in element 2B and 4 are almost identical with the important exception of the position of the

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* No Corresponding Therblig in this Element

contacts in the hand, and the way the contact points face on the spindle. Since these are diametrically opposed they could be expected to cause inhibition. The absence of evidence of positive transfer in element 2B, and the evidence of inhibition in element 4, lead to the conclusion that there were both positive transfer and inhibition present in element 2B, and inhibition in element 4, which was due to the similarity of the sequence of therbligs involved.

The basic difference in sequence of therbligs in element 3A may be accountable for the fact that inhibition did not completely obscure positive transfer, although again there were no statistically conclusive results.

The level of original or interpolated learning was found to have little effect upon habit facilitation and interference.

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

Conclusions: The smallness of the groups used in this experiment, and the variation due to individual differences in level of performance between operators masked any statistically significant differences between groups. A further limitation was the use of stop-watch methods, which in the hands of an inexperienced time study man are of questionable accuracy.

In spite of these limitations, however, there is sufficient evidence to conclude that positive transfer was evident in the elements which were the least similar to any other element or elements in the two operations, and that is positive transfer caused the first and second hours of practice of the groups with prior practice on a similar operation to assume some of the characteristics of the second and third hours of the groups without prior practice on a similar operation. The characteristics which were found to conform were the mean element times for the respective hours the decrement from one hour to the next, and the within hour range of time study means for each operator. The latter figure wasn't tested statistically because it was affected by operator stability within the hour long session.

Furthermore, it seems safe to conclude that inhibition was largely responsible for obscuring evidence of or preventing positive transfer on the elements which resembled other elements in the experiment very closely and that inhibition caused operator to perform significantly poorer in one operation than on another. In one of the common elements because of the presence of a very similar element in the operation in which performance was poorer.

Finally, when the varying similarity of these elements are compared in terms of the sequences of therbligs involved, it appears that the similarity of the sequence of therbligs is an important factor in determining if evidence of facilitation or interference appears.

The limited size of this experiment makes it impossible to say whether the level of original or interpolated learning has any effect on habit interference or facilitation. The magnitude of the effect due to the similarity of elements completely outweighed this factor.

Recommendations: This experiment was conducted on a broad basis to determine what facets of learning theory are most important in industrial learning, and what areas hold the most promise for future research. In the light of these objectives it has succeeded. Although the thesis experiment was statistically inconclusive, it indicated that the similarity of elements is an important factor in determining the extent to which transfer or inhibition take place.

Time is a limiting factor in masters thesis experiments, and so further research should concentrate on proving one or more closely related hypothesis and use as many volunteers as possible in order to make the experiment more sensitive in detecting significant results. A simple positive transfer experiment in which one group learns one operation, and then learns another while another group learns the same operations in reverse order, would go a long way in advancing what is known about learning theory.[4]

As a guide to further research along these lines, this writer would like to elaborate on Wolfler's hypothesis of similarity of stimuli and responses. (8) The proposal is that in industrial operations the sequence of therbligs in an operation constitute a series of stimuli and responses which act in the manner of backward conditioning, as well as in the usual stimulus-response manner, and that the greater the number of similar therbligs in two or more fundamental differences between the different therbligs' if interference is to be avoided. The evidence in this thesis tends to support this hypothesis, but cannot be construed as being significant. Therefore, this hypothesis is advanced as an unproven hypothesis meriting further study.

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[4] The use of motion picture film analysis is recommended in order to reveal what takes place when an operator's performance is inhibited or interfered with.

APPENDIX

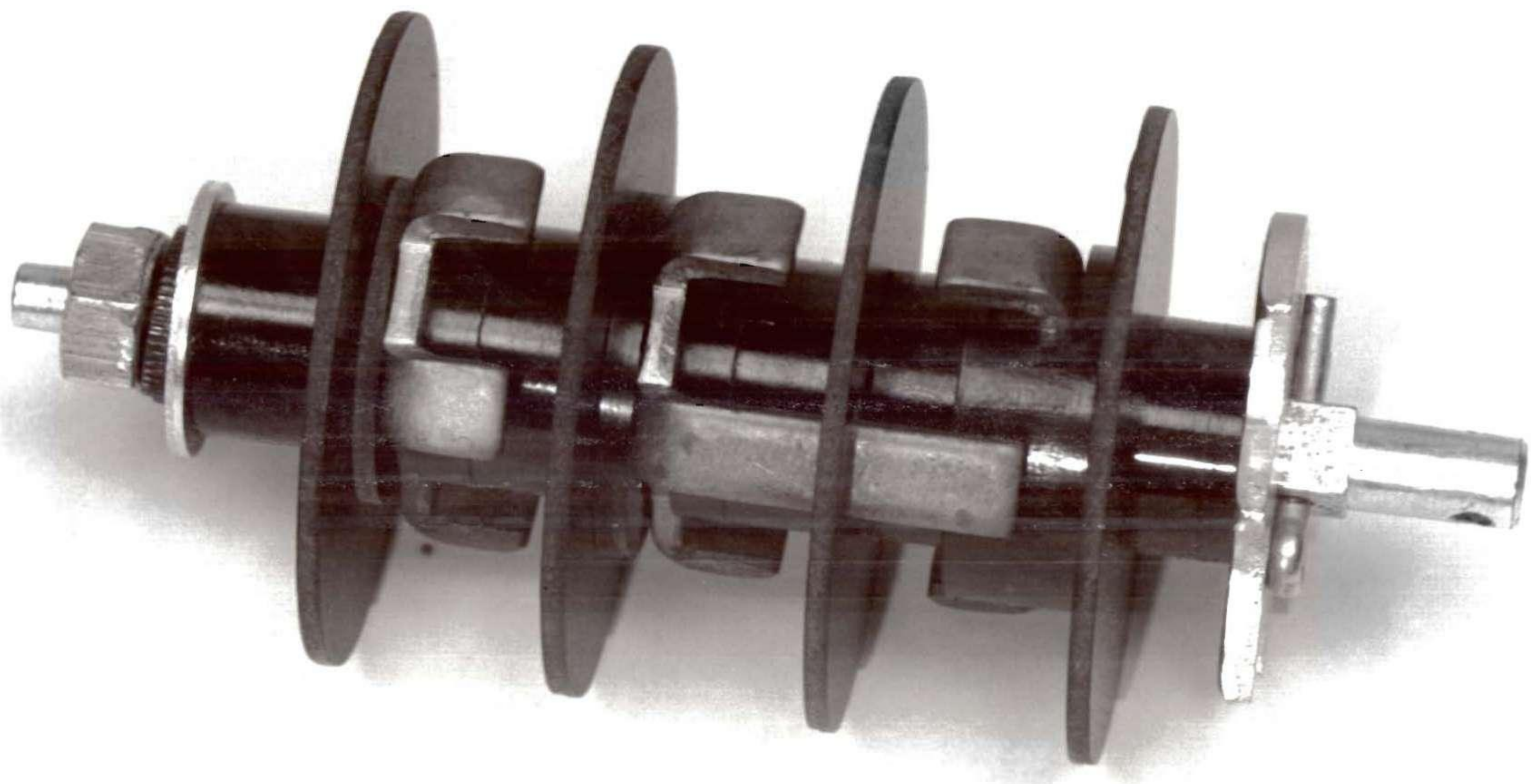

Fig. 8   R44 Drum Controller Rotor

First Week

Operator	Wednesday Feb. 22	Thursday Feb. 23	Friday Feb. 24	Saturday Feb. 25	Sunday Feb. 26
AC1	2:00	1:00	1:00	1:00	1:00
A11	3:30	3:30	2:30	2:30	2:30

Second Week

Operator	Monday Feb. 27	Tuesday Feb. 28	Wednesday Feb. 29	Thursday Mar. 1	Friday Mar. 2	Saturday Mar. 3	Sunday Mar. 4
A21	10:00	9:00	10:00	10:00	10:00	-	-
AC2	11:00	10:30	2:30	3:00	3:00	-	-
A12	4:00	4:00	4:00	4:00	4:00	-	-
A22	-	-	-	1:30	1:00-	1:00- 2:30	1:00- 2:30

Third Week

Operator	Monday Mar. 5	Tuesday Mar. 6	Wednesday Mar. 7	Thursday Mar. 8	Friday Mar. 9	Saturday Mar. 10
B11	10:00	10:30	10:00	10:30	10:00	-
B12	-	3:00	3:00	1:00	1:00	1:30

Fourth Week

Operator	Monday Apr. 2	Tuesday Apr. 3	Wednesday Apr. 4	Thursday Apr. 5	Friday Apr. 6
B21	11:00	11:30	11:00	11:30	11:00
B22	12:30	10:00	12:30	10:00	12:30

Figure 9 - Experiment Schedule

		Session				
Group	Operator	1	2	3	4	5
A C	1	107	155	178	190	198
	2	100	127	142	152	160
A 2	1	118	134	153*	156*	150
	2	87	105	146*	141*	124
A 1	1	87	132*	131	142*	140
	2	136	169*	184	230*	214
B 2	1	150*	185*	162	178	203*
	2	130*	156*	140	155	196*
B 1	1	134*	137	167*	156	180*
	2	153*	156	195*	176	212*

* Operation B performed during this hour

Figure 10 - Number of Assemblies Completed per hour

Element 1 Session Means ($\bar{\bar{x}}$) in minutes

Group	Operator	Session 1	2	3	4	5
A C	1	.078	.076	.064	.065	.059
	2	.094	.091	.072	.075	.070
A 2	1	.079	.070	.064	.057	.058
	2	.093	.082	.074	.084	.074
A 1	1	.088	.075	.074	.068	.070
	2	.071	.064	.057	.055	.049
B 2	1	.087	.061	.060	.054	.056
	2	.095	.083	.072	.073	.076
B 1	1	.083	.078	.074	.073	.073
	2	.076	.066	.061	.053	.059

Element 1 Session Ranges ($R_{\bar{x}}$) in Minutes

Group	Operator	Session 1	2	3	4	5
A C	1	.021	.007	.016	.011	.014
	2	.032	.034	.013	.010	.014
A 2	1	.031	.024	.009	.016	.007
	2	.019	.009	.013	.007	.012
A 1	1	.037	.023	.023	.002	.010
	2	.026	.021	.013	.006	.007
B 2	1	.023	.010	.004	.006	.010
	2	.017	.009	.026	.010	.024
B 1	1	.025	.011	.018	.015	.003
	2	.028	.018	.006	.006	.019

Figure 11 - Element Means and Ranges for Element 1

Element 2A Session Range ($R_{\overline{X}}$) in Minutes

Group	Operator	Session 1	2	3	4	5
A C	1	.011	.015	.001	.012	.015
	2	.048	.018	.012	.009	.002
A 2	1	.022	.017	--	--	.007
	2	.034	.004	--	--	.005
A 1	1	.043	--	.008	--	.007
	2	.018	--	.003	--	.004
B 2	1	--	--	.008	.003	--
	2	--	--	.010	.032	--
B 1	1	--	.019	--	.012	--
	2	--	.010	--	.000	--

Element 3A Session Range ($R_{\overline{X}}$) in Minutes

Group	Operator	Session 1	2	3	4	5
A C	1	.190	.043	.018	.021	.031
	2	.200	.041	.025	.008	.008
A 2	1	.129	.032	--	--	.028
	2	.134	.033	--	--	.033
A 1	1	.146	--	.059	--	.030
	2	.108	--	.033	--	.019
B 2	1	--	--	.076	.015	--
	2	--	--	.060	.038	--
B 1	1	--	.059	--	.016	--
	2	--	.049	--	.038	--

Figure 12 - Session Ranges for Elements 2A and 3A

Element 2B Session Range ($R_{\overline{x}}$)

Group	Operator	Session 1	2	3	4	5
A 2	1	-	-	.008	.023	-
	2	-	-	.022	.020	-
A 1	1	-	.007	-	.029	-
	2	-	.025	-	.019	-
B 2	1	.032	.006	-	-	.007
	2	.041	.007	-	-	.017
B 1	1	.023	-	.003	-	.012
	2	.020	-	.025	-	.018

Element 3B Session Range ($R_{\overline{x}}$)

Group	Operator	Session 1	2	3	4	5
A 2	1	-	-	.014	.015	-
	2	-	-	.019	.021	-
A 1	1	-	.012	-	.017	-
	2	-	.035	-	.004	-
B 2	1	.050	.010	-	-	.006
	2	.022	.018	-	-	.014
B 1	1	.021	-	.013	-	.011
	2	.048	-	.007	-	.010

Figure 13 - Session Ranges for Elements 2B and 3B

Element 4 Session Range ($R_{\overline{x}}$)

Group	Operator	Session 1	2	3	4	5
A C	1	.056	.011	.009	.008	.007
	2	.084	.024	.011	.019	.010
A 2	1	.068	.021	.012	.018	.021
	2	.072	.031	.004	.007	.007
A 1	1	.066	.046	.006	.004	.011
	2	.045	.033	.020	.024	.006
B 2	1	.056	.012	.012	.013	.013
	2	.030	.010	.029	.015	.010
B 1	1	.060	.022	.021	.003	.019
	2	.039	.031	.013	.007	.016

Figure 14 - Session Range for Element 4

Element 5 Session Means ($\overline{x}$) in Minutes

Group	Individual	Session 1	2	3	4	5
A C	1	.129	.083	.074	.062	.061
	2	.144	.102	.088	.082	.081
A 2	1	.135	.104	.094	.095	.092
	2	.155	.103	.086	.089	.081
A 1	1	.143	.111	.089	.095	.078
	2	.086	.083	.065	.060	.058
B 2	1	.100	.073	.067	.067	.064
	2	.136	.096	.092	.081	.071
B 1	1	.115	.088	.074	.071	.070
	2	.088	.081	.067	.083	.063

Element 5 Session Ranges ($R_{\overline{x}}$) in Minutes

Group	Individual	Session 1	2	3	4	5
A C	1	.138	.029	.022	.005	.013
	2	.118	.022	.014	.014	.017
A 2	1	.083	.015	.017	.019	.004
	2	.126	.022	.010	.013	.003
A 1	1	.075	.033	.015	.006	.007
	2	.049	.020	.014	.006	.011
B 2	1	.053	.005	.009	.008	.015
	2	.059	.021	.038	.018	.006
B 1	1	.059	.019	.002	.009	.005
	2	.027	.028	.019	.045	.004

Figure 15 - Element Means and Ranges for Element 5

$$X_{ijk} = \mu + C_i + R_j + CR_{ij} + O_{k(j)} + CO_{i(j)k}$$

Source	Mean Square	Degrees of Freedom	Estimated Variance Mean Square
Practice(Columns)	$\sum_i \frac{S^2_{ijk}}{JK} - \frac{S^2_{ijk}}{IJK}$	$(I - 1)$	$\sigma_{co}^2 + JK\sigma_c^2$
Groups (Rows)	$\sum_j \frac{S^2_{ijk}}{IK} - \frac{S^2_{ijk}}{IJK}$	$(J - 1)$	$I\sigma_o^2 + IK\sigma_R$
Group & Practice Interaction	$\sum_{ij} \frac{S^2_{ijk}}{IK} - \sum_i \frac{S^2_{ijk}}{JK} - \sum_j \frac{S^2_{ijk}}{IK} - \frac{S^2_{ijk}}{IJK}$	$(I-1)(J-1)$	$\sigma_{co}^2 + K\sigma_{CR}^2$
Operators	$\sum_{jk} \frac{S^2_{ijk}}{I} - \sum_j \frac{S^2_{ijk}}{IK}$	$J(K - 1)$	$I\,\sigma_o^2$
Operators and Practive	$\sum_{ijk} X^2_{ijk} - \sum_{ij} \frac{S^2_{ijk}}{IK} - \sum_{jk} \frac{S^2_{ijk}}{IK} + \sum_j \frac{S^2_{ijk}}{Ik}$	$(I-1)J(K-1)$	σ_{co}^2
Total	$\sum_{ijk} X^2_{ijk} - \frac{S^2_{ijk}}{IJK}$	$IJK - 1$	

I = No. of Practice Sessions or Columns (c) = 2
J = No. of Groups or Rows (R) = 4
K = No. of Operators per Group = 2

Figure 16 - Components of Variance for Elements 2A, 3A, 2B, and 3B.

Group	X Practice I	X Practice II	S	X^2 Practice I	X^2 Practice II	X^2		S^2
A 21	55	44	195	3025	1936	9577	99	9801
2	50	46		2500	2116		96	9216
A 11	72	45	193	5184	2025	10225	117	13689
2	46	30		2116	200		76	5776
B 21	44	35	172	1936	1225	7486	79	6241
2	46	47		2116	2209		93	8649
B 11	41	34	150	1681	1156	5654	75	5625
2	39	36		1521	1296		75	5625
	393	317	710	20079	12863	32942	710	64622

Group	Practice	X	
A2	I	105	11025
	II	90	8100
A1	I	118	13924
	II	75	5625
B2	I	90	8100
	II	82	6724
B1	I	80	6400
	II	70	4900

$$S^2_{ijk} = (710)^2 = 504100$$

$$\sum_j S^2_{ijk} = (393)^2 + (317)^2 = 254938$$

$$\sum_j S^2_{ijk} = (195)^2 + (193)^2 + (172)^2 + (150)^2 = 127358$$

$$\text{Variance of Practice Means} = \sum_j \frac{S^2_{ijk}}{JK} - \frac{S^2_{ijk}}{IJK} = \frac{254938}{4x2} - \frac{504100}{2x4x2} = 361$$

$$\text{Var. of Group Means} = \sum_j \frac{S^2_{ijk}}{IK} - \frac{S^2_{ijk}}{IJK} = \frac{127358}{2x2} - \frac{504100}{2x4x2} = 333$$

$$\text{Group \& Practice Interaction} = \sum_{ij} \frac{S^2_{ijk}}{K} - \sum_i \frac{S^2_{ijk}}{JK} - \sum_j \frac{S^2_{ijk}}{IK} + \frac{S^2_{ijk}}{IJK} = \frac{64798}{2}$$

$$- \frac{254938}{4x2} - \frac{127358}{2x2} + \frac{504100}{16} = 199$$

$$\text{Var. of Operators} = \sum_{jk} \frac{S^2_{ijk}}{I} - \sum_j \frac{S^2_{ijk}}{K} = 64622 - 127358 = 472$$

Figure 17 – Sample Calculations – Element 2A

$$\text{Operator \& Practice Interaction} = \sum_{ijk} X^2_{ijk} - \sum_{ij} \frac{S^2_{ijk}}{K} - \sum_{jk} \frac{S^2_{ijk}}{I} + \sum_{j} \frac{S^2_{ijk}}{JK}$$

$$= 32942 - \frac{64798}{2} - \frac{64622}{2} + \frac{127358}{4} = 71$$

$$\text{Total Variance} = \sum_{ijk} X^2_{ijk} - \frac{S^2_{ijk}}{IJK} = 32942 - 504100 = 1,436$$

Breaking the Group Variance into individual degrees of freedom gives:

$$\text{A vs B} \quad \frac{[(\overset{A\ 2}{+1})(\overline{195})+(\overset{A\ 1}{+1})(\overline{193})+(\overset{B\ 2}{-1})(\overline{172})+(\overset{B\ 1}{-1})(\overline{150})]^2}{4 \times 4} = 272.$$

$$\text{2 vs 1} \quad \frac{[(+1)(195)+(-1)(193)+(+1)(172)+(-1)(150)]^2}{4 \times 4} = 36.$$

$$\text{--} \quad \frac{[(+1)(195)+(-1)(193)+(-1)(172)+(+1)(150)]^2}{4 \times 4} = \underline{25}$$

$$333$$

Breaking Group and Practice Interaction into individual degrees of freedom gives:

$$\text{A vs B} \quad \frac{[(+1)(105-90)+(+1)(118-75)+(-1)(90-82)+(-1)(80-70)]^2}{4 \times 4} = 100$$

$$\text{1 vs 2} \quad \frac{[(+1)(105-90)+(-1)(118-75)+(+1)90-82)+(-1)(80-70)]^2}{4 \times 4} = 56$$

$$\text{--} \quad \frac{[(+1)(105-90)+(-1)(118-75)+(-1)(90-82)+(+1)(80-70)]^2}{4 \times 4} = \underline{42}$$

$$198.5$$

Figure 17 - Sample Calculations - 2A (continued)

The fourth element was broken into two separate analyses. The difference between the 1st and 2nd, and between the 3rd and 4th hours of practice were analyzed, using two columns with four groups, with two operators per group. The second analysis in which the 2nd to 3rd, and 4th to 5th hours were studied, will be explained on the next page, and below:

	X*			X^2			
Opr. to Opr.	2-3	4-5		2-3	4-5		
	95	99		9025	9801		
A to B	105	103	806	11025	10609	81,458	I = 2
	105	106		11025	11236		
	104	89		10816	7921		J = 2
	111	110		12301	12100		
B to A	128	107	884	16384	11449	98,184	K = 4
	98	109		9604	11881		
	107	114		11449	12996		
	853	837	1690	91649	87993	179,642	

Group	Column		
A to B	2-3	409	167,281
	4-5	397	157,609
B to A	2-3	444	197,136
	4-5	440	193,600
		1690	715,626

*Data Coded by adding 100 to each number to eliminate negative numbers.

$S^2{}_{ijk} = (1690)^2 = 2,856,100, \sum_i S^2{}_{ijk} = (853)^2 + (837)^2 = 1,428,178$

$\sum_j S^2{}_{ijk} = (806)^2 + (884)^2 = 1,431,092$

$\text{Var. Column Means} = \sum_i \frac{S^2{}_{ijk}}{JK} - \frac{S^2{}_{ijk}}{IJK} = \frac{1428178}{8} - \frac{2856100}{16} = 16$

$\begin{matrix}\text{Column \& Row}\\ \text{Interaction}\end{matrix} = \sum_{ij} \frac{S^2{}_{ijk}}{k} - \sum_i \frac{S^2_{ijk}}{JK} - \sum_j \frac{S^2{}_{ijk}}{IK} + \frac{S^2{}_{ijk}}{IJK} = \frac{715626}{4}$

$- \frac{1431092}{8} + \frac{2856100}{16} = 104$

Figure 18 - Sample Calculations - Element 4

$$\text{Within Boxes} = \sum_{ijk} X^2_{ijk} - \sum_{ij} \frac{S^2_{ijk}}{K} = 179642 - \frac{715626}{4} = 735$$

$$\text{Total variance} = \sum_{ijk} X^2_{ijk} - \frac{S^2_{ijk}}{IJK} = 179642 - \frac{2856100}{16} = 1136$$

The column, row, and column and row interaction were tested against the Within boxes variance.

Figure 18 - Sample Calculations - Element 4

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